# Integrated Silicon Platform for Co-planar Design of Vertically Stacked 2.06 THz Mixer Module

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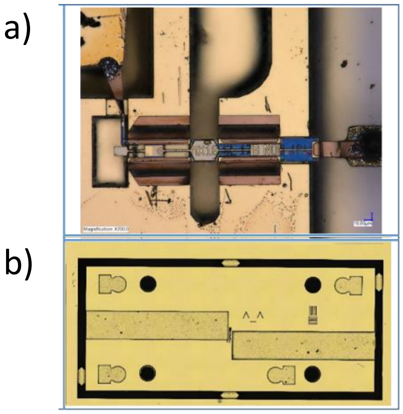
***Abstract*— A hybrid multiplier chain with a Si-micromachined stack housing the 2.06-THz sub-harmonic Schottky-diode based mixer is developed for the purpose of THz sensing for NASA in space. Low-noise temperature measurements are performed using this hybrid local-oscillator (LO) chain. The capability to have exact dimensionality becomes essential as frequency scales due to the complexity arising in assembly and finer tolerances. Total process yields can be improved through Si fabrication by verifying achievement of specified tolerances lithographically and compatibility to rapid process changes and design fine-tuning. The integrated Si platform is detailed, whereby signal I/O and alignment modalities enable low-noise measurements.**

***Index Terms*—Silicon, Space technology, Submillimeter wave propagation, System integration, Wafer scale integration**

## I. Introduction

UNDERSTANDING the atmospheric dynamics in Earth's upper atmosphere is an area of focus for NASA's earth science directorate [1]. Schottky diode mixers operating at several THz have historically been a stable method of passive sensing in space, with prior scientific mission deployments [2].

Figure 1. a) Device mounted in the Si block displayed in b). The beam lead of the diode is aligned to the center of the waveguide, and achieves precise alignment for complete coupling of the mode [3].



The capability to leverage silicon (Si) fabrication and integrate the local oscillator (LO) and intermediate frequency (IF) signal onto a compact Si micro-machined package has the potential to introduce new features and design paradigms.

A heterodyne receiver front end is being developed to perform measurements at 2.06 THz, where a neutral oxygen [OI] line exists. By measuring this atmospheric feature, thermos-spheric models can be created for understanding space weather and its impact on earth climate.

In this paper, we describe the process for fabricating and utilizing this three-dimensional Si stack receiver front-end. Silicon micromachining provides the necessary accuracy for integration at the several THz regime. Particularly, processing and etch recipes have demonstrated smooth surfaces of < 1 µm surface roughness. We keep in consideration pre-compensating for minute offsets, matching mechanical strain on all interfaces, and including passive alignment verification in the design. As compared to metal blocks, computer numerical controlled (CNC) milling can produce slight burrs in the interfaces resulting in misalignment and resultant strain between two pieces of components. Si integration can also make possible arrays of pixel transceivers through compact subsystems, drastically minimizing unit area.

## II. Background

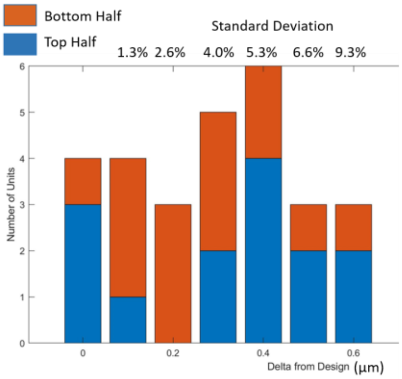
Silicon micromachining is used to create the fine waveguide features in the three-dimensional stack. The fabrication process consists of two main steps. In order to etch straight side walls, multiple $SiO_2$ masks are used. This type of process allows for thicker structures and multiple-levels for different feature heights [4]. The recipe used in this particular paper was first developed and described in [5] at Jet Propulsion Laboratory and adapted to be used for this work.

A three-step process for deep-reactive ion etching is performed. Negative photoresist is lithographically patterned on the 4-inch Si wafer. With the pre-determined selectivity of the process, inductively coupled plasma (ICP) etch is initially performed on the $SiO_2$. This step allows for finer precision over final target thicknesses. Then, deep-reactive ion etching (DRIE) is done, creating the desired depths of the Si waveguide. Waveguide depths are measured using a profilometer, in order ensure accuracy of process, which will be discussed further in the paper.

## III. SILICON INTEGRATION

The Si module, encompassing only a miniature area of 7.5 mm x 17.5 mm x .35 mm, is assembled in a hybrid package to interface to the rest of the metal chain. Within the module is housed a biased diode structure, as shown in Figure 1a, and the intermodulation frequency (IF) line. Two wafers of the design were fabricated, with fourteen top and bottom Si sets per wafer.

Fig. 2. The waveguide structure and its critical dimensions, mostly etch depths, are measured and their deviation from design are shown in this diagram. These values are well within tolerance of retaining optimal performance.



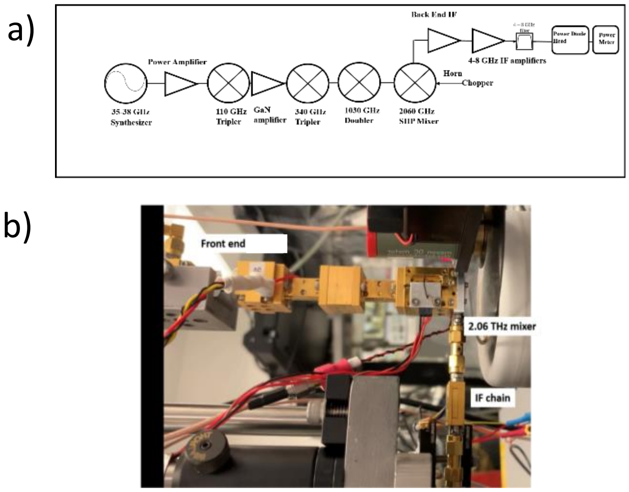
As discussed earlier, multi-step DRIE allows for Si micromachining of multiple depths with precision and smoothness. Other features shown in the waveguide picture in Figure 1b are designed to be within their required depths, as well as match complementary etch depths.

The exact dimensions are met with accuracy by reduced etches and checks with the calibrated Dektak profilometer. Figure 2 illustrates the delta from designed waveguide depth measured across wafer.

## IV. EXPERIMENTAL RESULTS

Experimental results are demonstrated using the LO chain, represented by Figure 3, consisting of a National Instruments synthesizer source amplified by a Cernex power amplifier to drive the 110 GHz tripler and a Gallium Nitride (GaN) amplifier. From here, the signal is launched into the 340 GHz tripler, followed by a 1 THz doubler providing 1 milliwatt (mW) of power at various frequency points into the 2.06 THz subharmonic mixer.

Fig. 3. Block diagram of experimental setup for room temperature measurements b) Picture of setup during noise temperature measurement, with the 2.06 THz mixer at the rightmost end of the local oscillator chain.



In Silicon, with RF pumping at 1.987 THz, the mounted diode is operational with > 0.150 mA current at 1.3 V reverse bias. For the balanced diode, with series resistance in the 100 to 170 Ω range, noise temperature measurements are predicted to be in a similar to lower range as the demonstration in the metal waveguide enclosure.

## V. CONCLUSION

NASA has as one of its central goals to model thermo-spheric dynamics, and this work provides the necessary technology to enable the measurement of this spectral characteristic.

The advantage of utilizing this Si process for space technology is twofold. Beyond rapid prototyping, the designed stack is ready for flight demonstrations and extensible to array form. This particular interface will be directly applied to the detection of the OI line, which occurs at 2.06 THz frequency.

Prior measurements at > 2 THz have not been at room temperature, which is targeted with this heterodyne detection scheme [6] for reduced power consumption.

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